Aerial Vehicle Routing and Scheduling for UAS Traffic Management: A Monte Carlo Tree Search Approach

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Numerous unmanned aircraft systems operating at low altitudes to deliver goods and services may one day become ubiquitous in our cities. In the Unmanned Aircraft Systems (UAS) Traffic Management (UTM) framework, such a concept is envisioned, where aerial vehicles operate beyond visual line of sight (BVLOS) within specifically reserved and time stamped "corridors" in the airspace. For example, these corridors or operational intent volumes can connect an aerial vehicle's origin site to its destination site for package delivery operations. There may also be more than one corridor available for an aerial vehicle to choose from and often different corridors may intersect with one another. Thus, it is imperative to ensure flight trajectories belonging to different aerial vehicles are not in conflict. Per the UTM CONOPs, we assume that a vehicle almost always stays inside its corridor or operational volume. So, to prevent collisions, we only need to de-conflict the operational volumes corresponding to two different vehicles; either the volumes are de-conflicted in space or in time. This can primarily be achieved by carefully adjusting the times of arrival of the aircraft at the points of conflict (e.g., intersection of corridors). So, we impose a minimum temporal separation constraint at the intersection between any two aircraft arriving at the intersection along two different corridors.

This work provides a framework for strategic deconfliction of UTM or package delivery drones, where we schedule the departure time of all vehicles subject to various temporal constraints (including the corridor deconfliction at the intersections). We present the "multi-route weighted package delivery problem" which serves as an exemplifying model for strategic deconfliction in UTM. In the multi-route weighted package delivery problem, a graph network is given which consists of a set of depots (source) and drop-off (destination) nodes, with multiple routes (defined as a sequence of waypoints) connecting the depots to drop-off nodes. In addition, routes are weighted by the associated ground risk and total travel distance for package delivery. The goal is for a known set of aerial vehicles to depart from the depots, choose a route and take off time, while avoiding conflicts with other aerial vehicles, and minimizing both risk and distance traveled. We provide a mixed integer linear programming (MILP) formulation of the problem, as well as a heuristic solution based on Monte Carlo Tree Search (MCTS) – a method used in game theory and artificial intelligence – to overcome limitations inherent to optimal solvers.

Computational results show the advantages of using MCTS over the MILP formulation; the former can provide a sub-optimal solution quickly, and may sometimes even reach an optimal solution, whereas the latter may not even produce a solution in reasonable time. Furthermore, results from both the MILP formulation and MCTS methods were validated using a preliminary agent-based simulator implementing the UTM concept of operations. Thus, the MCTS method can be seen as a scalable solution to the complex multi-route weighted package delivery problem and may possibly be extended to similar complex optimization problems.